GEI Consultants

Calculation Cover Sheet

GEI Project	TIMET	
GEI Project Number	1323080	
ENGINEER-STATE OF NEVADA PROFESSIONAL JOHN M. TRAST Exp: 6/30/2014 CIVIL No. 22661	By: Karl Krueger	Date: 2/27/2014
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PURPOSE OF CALCULATIONS

The TIMET ponds are designed with outer sideslopes ranging from 2.5H:1V to 3.0H:1V, with a maximum vertical rise of approximately 20 feet. The sideslope is to be protected with a GCL, a layer of bedding stone, and a layer of riprap. This analysis evaluates the stability of the sideslope protection system during placement of the bedding stone layer, as well as long term stability of the sideslope protection system.

METHOD

The slope was analyzed as an infinite slope. Slope failure would occur as a plane sliding along a critical interface. The potential sliding interfaces are between the GCL and the bedding stone, and between the bedding stone and riprap. A design factor of safety of 1.5 is used for long-term steady state conditions. 1.3 is used for peak strength analysis under short-term equipment loading during construction. 1.0 is used for residual strength analysis under short-term loading. These factors of safety are considered appropriate based on experience of common geotechnical engineering practice.

For the short-term equipment loading condition, a CAT D5K LGP bulldozer was evaluated. The weight of the equipment is assumed to be 21,266 pounds. It is assumed that the bulldozer will place the bedding stone layer only. It is assumed that riprap will be placed using a long reach excavator. This results in no equipment loading on the slope during riprap placement. Therefore the critical construction time is during placement of the bedding stone layer.

RESULTS

The minimum required friction angle for each of the design conditions is presented in the following table:

	2.5H:1V	3.0H:1V
	Required ϕ	Required ϕ
Peak Strength With Equipment Loading (FS=1.3)	31	26
Long-Term (FS=1.5)	31	26
Residual Strength With Equipment Loading (FS=1.0)	25	21

Alternatively, the minimum required shear strength for each of the design conditions is presented in the following table:

	2.5H:1V	3.0H:1V
	Required Shear Strength (psf)	Required Shear Strength (psf)
Peak Strength With Equipment Loading (FS=1.3)	79	61
Long-Term (FS=1.5)	37	31
Residual Strength With Equipment Loading (FS=1.0)	60	47

A GCL with nonwoven geotextile on both sides, such as Bentomat DN, GSE BentoLiner NWL, or equivalent, should generally have a higher interface friction with soil than a GCL with a woven or slit film geotextile on one side. It is recommended that a GCL with nonwoven geotextile on both sides be used to provide a greater factor of safety against veneer stability.

Interface and internal shear strength test results should be performed at the time of construction, and should be reviewed by a qualified engineer to determine if the material is equivalent to the stated values in the tables above.

Slope Stability of Slope Protection System

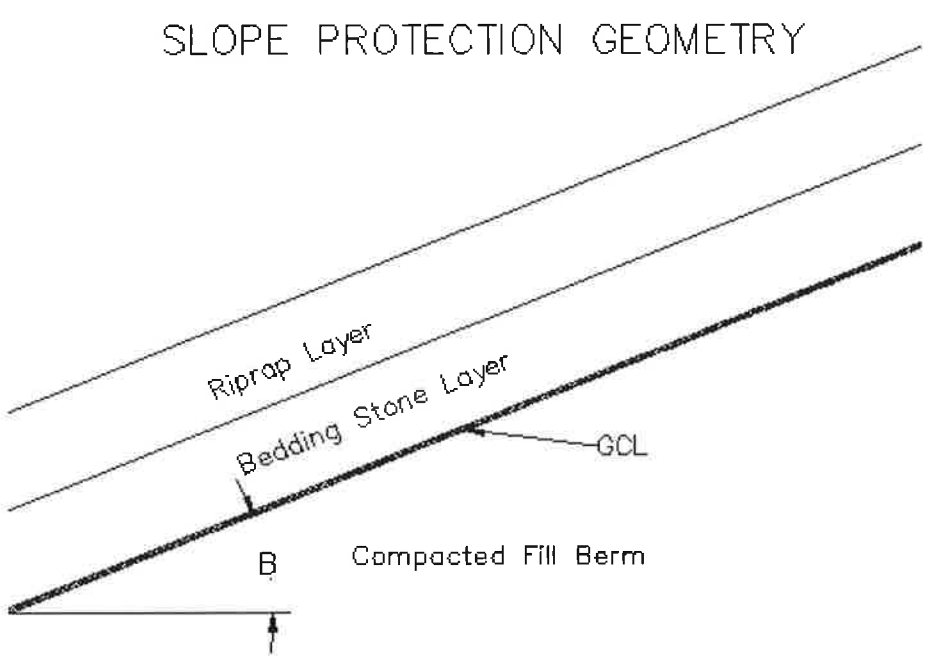
Unknown units for Mathcad Program

$pcf := \frac{lb}{ft^3}$ $psf := \frac{lb}{ft^2}$ $psi := \frac{lb}{in^2}$ $R := \theta \cdot \frac{\pi}{180}$

Slope Protection Stability Analysis

The TIMET Ponds are designed with a 2.5H:1V outer sideslopes with a maximum vertical rise of approximately 20 feet. The sideslope stability is dependent on the shear strength developed from the interface friction of the slope protection components. The critical time for stabiity of the slope is during construction, when equipment is placing bedding stone over the GCL. The different layers of the slope protection system consist of, from bottom to top, a compacted granular fill berm, a GCL, a 0.5-foot bedding stone layer, and a riprap layer. This analysis evaluates the stability of the slope protection system during placement of the bedding stone layer.

Profile



The slope of the system is 2.5H:1V, resulting in an angle of approximately 22 degrees

$\beta := 22\text{deg} \qquad \beta = 0.384 \cdot \text{rad}$

The maximum height of the berm is approximately 20 feet, resulting in a slope length of approximately 54 feet.

$L_s := 54\text{ft}$

Material Properties:

The compacted fill has an assumed internal angle of friction, ϕ_{fill}, of 35 degrees, and a cohesion of 0.

The bedding stone layer has an assumed unit weight, γ_{stone}, of 130 pcf, an internal friction angle, ϕ_{stone}, of 32 degrees, and a cohesion of 0.

The riprap layer has an assumed unit weight, γ_{rip}, of 130 pcf, an internal friction angle, ϕ_{rip}, of 35 degrees, and a cohesion of 0.

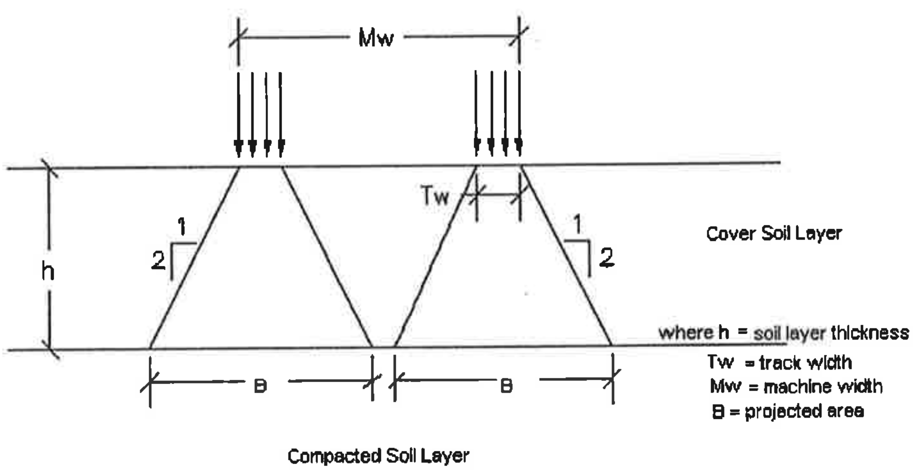
$\phi_{fill} := 35\text{deg}$

$\gamma_{stone} := 130\text{pcf} \qquad \phi_{stone} := 32\text{deg}$

$\gamma_{rip} := 130\text{pcf} \qquad \phi_{rip} := 35\text{deg}$

Design Vehicle Loading Condition

The weight of the vehicle is projected onto the surface of the GCL as shown below:



For the vehicle loading condition, the use of a CAT D5K2 bulldozer will be evaluated.

The weight of the vehicle on the slope surface is assumed to be 21,266 pounds for a CAT D5K LGP bulldozer. The projected imprint area onto the surface of the GCL is calculated as:

$$B := T_w + 2 \cdot P_w$$

where T_w = width of the track
P_w = extra width projected through layer thickness

$$h := 0.5\text{ft} \qquad P_w := \frac{h}{2}$$

$$T_w := 2.16\text{ft} \qquad P_w = 0.25 \cdot \text{ft}$$

$$B := T_w + 2P_w \qquad B = 2.66 \cdot \text{ft}$$

The line load due to the projected vehicle weight is aassumed to be applied to the entire slope. The weight of the vehicle on the GCL surface is:

$$W_{eq} := 21266\text{lb}$$

$$W_{line} := \frac{W_{eq}}{2B}$$

$$W_{line} = 3.997 \times 10^3 \cdot \frac{\text{lb}}{\text{ft}}$$

Analysis:

The sideslope stability analysis assumes that the slope is infinite. Slope failure would occur as a plane sliding along a critical interface.

A design factor of safety of 1.5 is used for long term steady state conditions, 1.3 is used for peak strength analysis under equipment loading, and 1.0 for residual strength under equipment loading (Duncan, 1987). These factors of safety are considered appropriate based on experience of common geotechnical practice.

For an infinite slope, the factor of safety is the ratio of resisting forces to driving forces. The equation is shown below.

$$FS := \frac{F_R}{F_D}$$

where F_R = Resisting Forces
F_D = Driving Forces

The driving forces for the static condition are:

$$F_D := W \cdot \sin(\beta)$$

$$F_D := \gamma_{stone} \cdot h \cdot L_s \cdot \sin(\beta)$$

Where W = weight of cover soils
γ = unit weight of cover soils
h = thickness of cover soil
L = length of slope
β = angle of the slope

$$F_D = 1.315 \times 10^3 \cdot \frac{lb}{ft}$$

Taking into consideration the weight of the bulldozer, the driving force during construction (F_{Ddozer}) is:

$$F_{Ddozer} := W_{line} \cdot \sin(\beta)$$

$$F_{Ddozer} = 1.497 \times 10^3 \cdot \frac{lb}{ft}$$

To account for the additional force due to braking, the driving force due to the dozer is increased by 30%

$$F_{Dbraking} := F_{Ddozer} \cdot 1.3$$

$$F_{Dbraking} = 1.947 \times 10^3 \cdot \frac{lb}{ft}$$

The total driving force is calculated as:

$$F_{Dtotal} := F_D + F_{Dbraking}$$

$$F_{Dtotal} = 3.262 \times 10^3 \cdot \frac{lb}{ft}$$

The resisting forces are:

$$F_R := F_S + F_G + F_B + F_{Dozer}$$

where F_S = friction resistance force of soil
F_G = tensile strength of GCL
F_B = soil buttressing force

The friction resistance force is defined as:

$$F_S := \left[\left(\gamma_{stone} \cdot h \cdot L_s\right) \cdot \cos(\beta)\right] \cdot \tan\left(\phi_{min}\right)$$

The minimum required friction angle (ϕ_{min}) will be solved for.

The soil buttressing force is defined as:

$$F_B := \frac{\cos\left(\phi_{stone}\right)}{\cos\left(\phi_{stone} + \beta\right)} \cdot \left(\frac{\gamma_{stone} \cdot h^2}{\sin(2 \cdot \beta)} \cdot \tan\left(\phi_{stone}\right)\right)$$

$$F_B \rightarrow \frac{32.5 \cdot lb \cdot \cos(32 \cdot deg) \cdot \tan(32 \cdot deg)}{ft \cdot \cos(54 \cdot deg) \cdot \sin(44 \cdot deg)} \qquad F_B = 42 \cdot \frac{lb}{ft}$$

The buttressing force is negligible, so it will not be included in the total resisting force.

$$F_B \equiv 0 \frac{lb}{ft}$$

No tensile strength for the geosynthetics was included to allow for the GCL to be installed in a relaxed condition.

$$F_G := 0 \frac{lb}{ft}$$

The weight of the bulldozer serves as an additional resisting force, by contributing additional normal force to the friction component.

$$F_{Rdozer} := W_{line} \cdot \cos(\beta) \cdot \tan\left(\phi_{min}\right)$$

The minimum required friction angle (ϕ_{min}) will be solved for.

For peak strength with equipment loading, use FS=1.3 for short term loading:

The required minimum friction angle for the liner system can be found by solving the factor of safety equation. Using a factor of safety of 1.3 for maximum strength evaluation, the required friction angle is:

$$FS := \frac{F_{Rtotal}}{F_{Dtotal}} \qquad FS_1 := 1.3 \qquad 1.3 := \frac{F_S + F_{Rdozer}}{F_{Dtotal}}$$

$$T_{\phi min1} := \frac{1.3 \cdot F_{Dtotal}}{\gamma_{stone} \cdot h \cdot L_s \cdot \cos(\beta) + W_{line} \cdot \cos(\beta)}$$

$$T_{\phi min1} = 0.609$$

$$\phi_{min1} := \operatorname{atan}\left(T_{\phi min1}\right)$$

$$\phi_{min1} = 31.3 \cdot deg$$

Alternatively, the minimum peak shear strength required is:

$$S_{min1} := 1.3 \cdot \frac{F_{Dtotal}}{L_s} \qquad S_{min1} = 78.5 \cdot psf$$

For peak strength WITHOUT equipment loading, use FS=1.5 for long term conditions:

$$T_{\phi min2} := \frac{1.5 \cdot F_D}{\gamma_{stone} \cdot h \cdot L_s \cdot \cos(\beta)}$$

$$T_{\phi min2} = 0.606$$

$$\phi_{min2} := \operatorname{atan}\left(T_{\phi min2}\right)$$

$$\phi_{min2} = 31.2 \cdot deg$$

Alternatively, the minimum peak shear strength required is:

$$S_{min2} := 1.5 \cdot \frac{F_D}{L_s} \qquad S_{min2} = 36.5 \cdot psf$$

The required minimum friction angle for peak strength conditions is 31 degrees, or alternatively the minimum required peak shear strength is 79 psf.

For residual strength, with equipment loading, use FS=1.0:

$$FS_{res} := \frac{F_{Rtotal}}{F_{Dtotal}} \qquad FS_{res} := 1.0 \qquad 1.0 := \frac{F_S + F_{Rdozer}}{F_{Dtotal}}$$

$$T_{\phi res} := \frac{1.0 \cdot F_{Dtotal}}{\gamma_{stone} \cdot h \cdot L_s \cdot \cos(\beta) + W_{line} \cdot \cos(\beta)}$$

$$T_{\phi res} = 0.469$$

$$\phi_{res} := \operatorname{atan}\left(T_{\phi res}\right)$$

$$\phi_{res} = 25.1 \cdot deg$$

Alternatively, the minimum peak shear strength required is:

$$S_{res} := 1.0 \cdot \frac{F_{Dtotal}}{L_s} \qquad S_{res} = 60.4 \cdot psf$$

The required minimum friction angle for residual strength conditions is 25 degrees, or alternatively the minimum required peak shear strength is 60 psf.

Recommendations:

A GCL with nonwoven geotextile on both sides, such as Bentomat DN, GSE BentoLiner NWL, or equivalent, will generally have a higher interface friction with soil than a GCL with a woven or slit film on one side. It is recommended that a GCL with nonwoven geotextile on both sides be used to provide a greater factor of safety against veneer stability.

Interface and internal shear strength test results performed at the time of construction should be reviewed by a qualified engineer to determine if equivalent to the stated values.

References:

Duncan, J.M. Buchigani, A.Land DeWet, M. "An Engineering Manual for Slope Stability Studies," Department of Civil Engineering, Virginia Polytechnic Institute and State University. 1987.

Gilbert, R.B. "Peak Versus Residual Strength for Waste Containment Systems," Proceedings of the 15th GRI Conference on Hot Topics in Geosynthetics II. December 2001.

Theil, R.S. "Peak Vs. Residual Shear Strength for Bottom Liner Stability Analysis," Proceedings of the 15th GRI Conference on Hot Topics in Geosynthetics II. December 2001.

Slope Stability of Slope Protection System

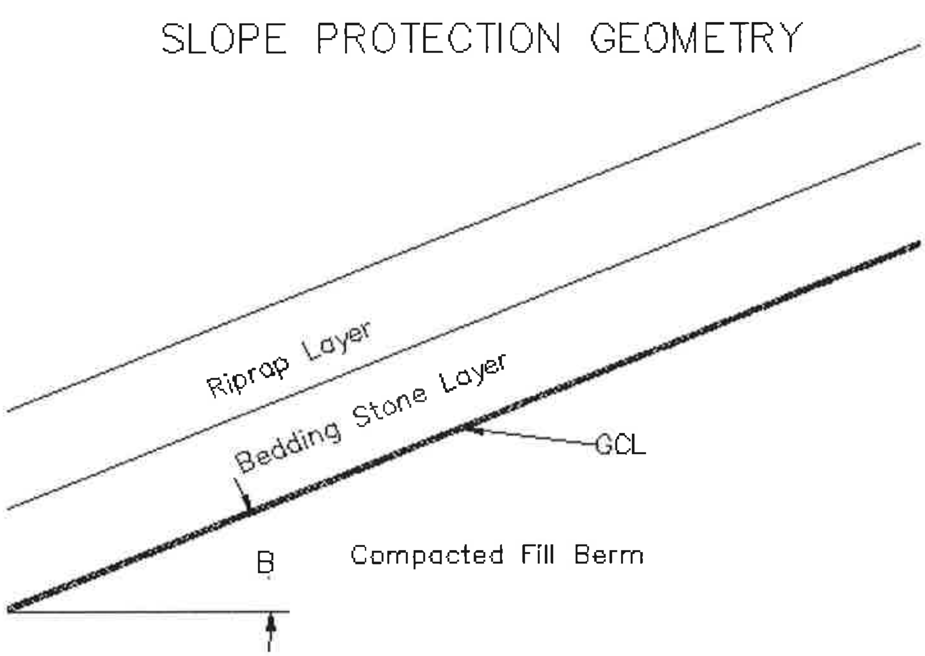
Unknown units for Mathcad Program

$$pcf := \frac{lb}{ft^3} \qquad psf := \frac{lb}{ft^2} \qquad psi := \frac{lb}{in^2} \qquad R := \theta \cdot \frac{\pi}{180}$$

Slope Protection Stability Analysis

The TIMET Ponds are designed with a 3.0:1V outer sideslopes with a maximum vertical rise of approximately 20 feet. The sideslope stability is dependent on the shear strength developed from the interface friction of the slope protection components. The critical time for stabiity of the slope is during construction, when equipment is placing bedding stone over the GCL. The different layers of the slope protection system consist of, from bottom to top, a compacted granular fill berm, a GCL, a 0.5-foot bedding stone layer, and a riprap layer. This analysis evaluates the stability of the slope protection system during placement of the bedding stone layer.

Profile



The slope of the system is 3.0H:1V, resulting in an angle of approximately 18.4 degrees

$\beta := 18.4\text{deg} \qquad \beta = 0.321 \cdot \text{rad}$

The maximum height of the berm is approximately 20 feet, resulting in a slope length of approximately 63 feet.

$L_s := 63\text{ft}$

Material Properties:

The compacted fill has an assumed internal angle of friction, ϕ_{fill}, of 35 degrees, and a cohesion of 0.

The bedding stone layer has an assumed unit weight, γ_{stone}, of 130 pcf, an internal friction angle, ϕ_{stone}, of 32 degrees, and a cohesion of 0.

The riprap layer has an assumed unit weight, γ_{rip}, of 130 pcf, an internal friction angle, ϕ_{rip}, of 35 degrees, and a cohesion of 0.

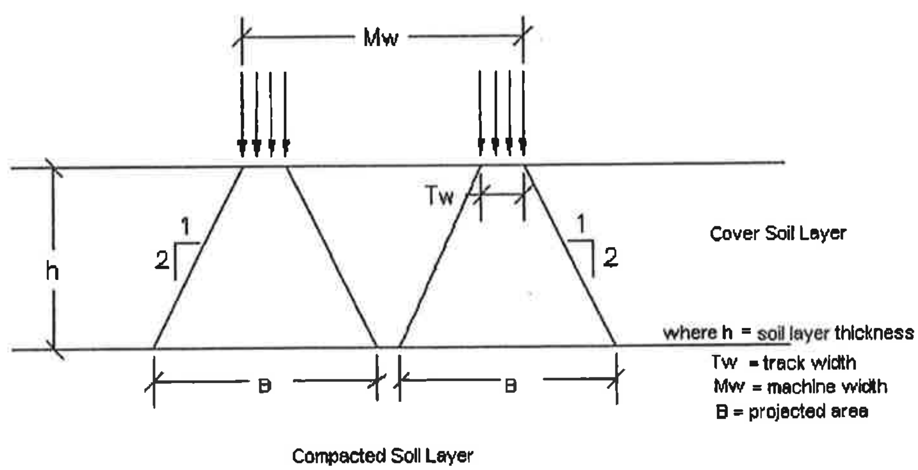
$\phi_{fill} := 35\text{deg}$

$\gamma_{stone} := 130\text{pcf} \qquad \phi_{stone} := 32\text{deg}$

$\gamma_{rip} := 130\text{pcf} \qquad \phi_{rip} := 35\text{deg}$

Design Vehicle Loading Condition

The weight of the vehicle is projected onto the surface of the GCL as shown below:



For the vehicle loading condition, the use of a CAT D5K LGP bulldozer will be evaluated.

The weight of the vehicle on the slope surface is assumed to be 21,266 pounds for a CAT D5K LGP bulldozer. The projected imprint area onto the surface of the GCL is calculated as:

$$B := T_w + 2 \cdot P_w$$

where T_w = width of the track
P_w = extra width projected through layer thickness

$h := 0.5\text{ft}$ $\quad P_w := \dfrac{h}{2}$

$T_w := 2.16\text{ft}$ $\quad P_w = 0.25 \cdot \text{ft}$

$B := T_w + 2P_w$ $\quad B = 2.66 \cdot \text{ft}$

The line load due to the projected vehicle weight is aassumed to be applied to the entire slope. The weight of the vehicle on the GCL surface is:

$$W_{eq} := 21266\text{lb}$$

$$W_{line} := \frac{W_{eq}}{2B}$$

$$W_{line} = 3.997 \times 10^3 \cdot \frac{\text{lb}}{\text{ft}}$$

Analysis:

The sideslope stability analysis assumes that the slope is infinite. Slope failure would occur as a plane sliding along a critical interface.

A design factor of safety of 1.5 is used for long term steady state conditions, 1.3 is used for peak strength analysis under equipment loading, and 1.0 for residual strength under equipment loading (Duncan, 1987). These factors of safety are considered appropriate based on experience of common geotechnical practice.

For an infinite slope, the factor of safety is the ratio of resisting forces to driving forces. The equation is shown below.

$$FS := \frac{F_R}{F_D}$$

where F_R = Resisting Forces
F_D = Driving Forces

The driving forces for the static condition are:

$$F_D := W \cdot \sin(\beta)$$

$$F_D := \gamma_{stone} \cdot h \cdot L_s \cdot \sin(\beta)$$

Where W = weight of cover soils
γ = unit weight of cover soils
h = thickness of cover soil
L = length of slope
β = angle of the slope

$$F_D = 1.293 \times 10^3 \cdot \frac{lb}{ft}$$

Taking into consideration the weight of the bulldozer, the driving force during construction (F_{Ddozer}) is:

$$F_{Ddozer} := W_{line} \cdot \sin(\beta)$$

$$F_{Ddozer} = 1.262 \times 10^3 \cdot \frac{lb}{ft}$$

To account for the additional force due to braking, the driving force due to the dozer is increased by 30%

$$F_{Dbraking} := F_{Ddozer} \cdot 1.3$$

$$F_{Dbraking} = 1.64 \times 10^3 \cdot \frac{lb}{ft}$$

The total driving force is calculated as:

$$F_{Dtotal} := F_D + F_{Dbraking}$$

$$F_{Dtotal} = 2.933 \times 10^3 \cdot \frac{lb}{ft}$$

The resisting forces are:

$$F_R := F_S + F_G + F_B + F_{Dozer}$$

where F_S = friction resistance force of soil
F_G = tensile strength of GCL
F_B = soil buttressing force

The friction resistance force is defined as:

$$F_S := \left[\left(\gamma_{stone} \cdot h \cdot L_s\right) \cdot \cos(\beta)\right] \cdot \tan\left(\phi_{min}\right)$$

The minimum required friction angle (ϕ_{min}) will be solved for.

The soil buttressing force is defined as:

$$F_B := \frac{\cos\left(\phi_{stone}\right)}{\cos\left(\phi_{stone} + \beta\right)} \cdot \left(\frac{\gamma_{stone} \cdot h^2}{\sin(2 \cdot \beta)} \cdot \tan\left(\phi_{stone}\right)\right)$$

$$F_B \rightarrow \frac{32.5 \cdot lb \cdot \cos(32 \cdot deg) \cdot \tan(32 \cdot deg)}{ft \cdot \cos(50.4 \cdot deg) \cdot \sin(36.8 \cdot deg)} \qquad F_B = 45 \cdot \frac{lb}{ft}$$

The buttressing force is negligible, so it will not be included in the total resisting force.

$$F_B \equiv 0 \frac{lb}{ft}$$

No tensile strength for the geosynthetics was included to allow for the GCL to be installed in a relaxed condition.

$$F_G := 0 \frac{lb}{ft}$$

The weight of the bulldozer serves as an additional resisting force, by contributing additional normal force to the friction component.

$$F_{Rdozer} := W_{line} \cdot \cos(\beta) \cdot \tan\left(\phi_{min}\right)$$

The minimum required friction angle (ϕ_{min}) will be solved for.

For peak strength with equipment loading, use FS=1.3 for short term loading:

The required minimum friction angle for the liner system can be found by solving the factor of safety equation. Using a factor of safety of 1.3 for maximum strength evaluation, the required friction angle is:

$$FS := \frac{F_{Rtotal}}{F_{Dtotal}} \qquad FS_1 := 1.3 \qquad 1.3 := \frac{F_S + F_{Rdozer}}{F_{Dtotal}}$$

$$T_{\phi min1} := \frac{1.3 \cdot F_{Dtotal}}{\gamma_{stone} \cdot h \cdot L_s \cdot \cos(\beta) + W_{line} \cdot \cos(\beta)}$$

$$T_{\phi min1} = 0.497$$

$$\phi_{min1} := \operatorname{atan}\left(T_{\phi min1}\right)$$

$$\phi_{min1} = 26.4 \cdot deg$$

Alternatively, the minimum peak shear strength required is:

$$S_{min1} := 1.3 \cdot \frac{F_{Dtotal}}{L_s} \qquad S_{min1} = 60.5 \cdot psf$$

For peak strength WITHOUT equipment loading, use FS=1.5 for long term conditions:

$$T_{\phi min2} := \frac{1.5 \cdot F_D}{\gamma_{stone} \cdot h \cdot L_s \cdot \cos(\beta)}$$

$$T_{\phi min2} = 0.499$$

$$\phi_{min2} := \operatorname{atan}\left(T_{\phi min2}\right)$$

$$\phi_{min2} = 26.5 \cdot deg$$

Alternatively, the minimum peak shear strength required is:

$$S_{min2} := 1.5 \cdot \frac{F_D}{L_s} \qquad S_{min2} = 30.8 \cdot psf$$

The required minimum friction angle for peak strength conditions is 27 degrees, or alternatively the minimum required peak shear strength is 61 psf.

For residual strength, with equipment loading, use FS=1.0:

$$FS_{res} := \frac{F_{Rtotal}}{F_{Dtotal}} \qquad FS_{res} := 1.0 \qquad 1.0 := \frac{F_S + F_{Rdozer}}{F_{Dtotal}}$$

$$T_{\phi res} := \frac{1.0 \cdot F_{Dtotal}}{\gamma_{stone} \cdot h \cdot L_s \cdot \cos(\beta) + W_{line} \cdot \cos(\beta)}$$

$$T_{\phi res} = 0.382$$

$$\phi_{res} := \operatorname{atan}\left(T_{\phi res}\right)$$

$$\phi_{res} = 20.9 \cdot deg$$

Alternatively, the minimum peak shear strength required is:

$$S_{res} := 1.0 \cdot \frac{F_{Dtotal}}{L_s} \qquad S_{res} = 46.6 \cdot psf$$

The required minimum friction angle for residual strength conditions is 21 degrees, or alternatively the minimum required peak shear strength is 47 psf.

Recommendations:

A GCL with nonwoven geotextile on both sides, such as Bentomat DN, GSE BentoLiner NWL, or equivalent, will generally have a higher interface friction with soil than a GCL with a woven or slit film on one side. It is recommended that a GCL with nonwoven geotextile on both sides be used to provide a greater factor of safety against veneer stability.

Interface and internal shear strength test results performed at the time of construction should be reviewed by a qualified engineer to determine if equivalent to the stated values.

References:

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